This study investigated the bone-to-implant contact (BIC) and osteoconductive capacity (OC) of 6 different implant surfaces after early loading in humans. Two implants with different surfaces were placed side-by-side in the grafted (n = 5) and nongrafted (n = 1) sinuses of 3 volunteers. Single-tooth restorations were delivered 60 days later. After 6 months of full occlusal loading, implants were retrieved in block sections for histomorphometric analysis. One implant (acid etched) placed in grafted bone failed when loaded. There were no other complications. In grafted bone, the microtextured surface achieved the highest BIC value (94.08%), followed by the oxidized (77.32%), hydroxyapatite (HA) (74.51%), sandblasted and acid-etched (51.85%), and titanium plasma-sprayed (TPS) (41.48%) surfaces. In native bone, the acid-etched surface achieved a higher BIC value (69.03%) than the HA surface (59.03%). The highest OC value in grafted bone was exhibited by the microtextured surface (34.31%), followed by the HA (28.62%), sandblasted and acid-etched (25.08%), oxidized (17.55%), and TPS (20.47%) surfaces. The HA surface exhibited a higher OC value (30.39%) in native bone compared with the acid-etched surface (24.0%). As a whole, highest BIC and OC values were exhibited by the microtextured surface, and lowest values were exhibited by the TPS surface. All other surfaces demonstrated excellent BIC (>50%) but varied in OC (range = 17.55%–28.62%). These findings are tempered by the limited scope and sample size of the study and should be considered preliminary. More research is needed to determine the impact of implant surface texture on BIC and OC.


**INTRODUCTION**

Dental implant surfaces affect the hard and soft tissues during wound healing and osseointegration, but their full influence on cellular events is not yet entirely understood. The topography of the implant surface directly affects cell shape and function and guides the locomotion and orientation of specific cell types. Implant surface microtexture or roughness also appears to be an important variable in the percentage of hard tissue apposition, often called bone-to-implant contact (BIC) in the dental literature, that develops during osseointegration. The degree to which implant surface topography can serve as a scaffold for the regenerating bone tissue without an active role in actual bone formation has been termed the osteoconductive capacity (OC) of the surface and has been calculated histomorphometrically as the difference between the percentage of BIC and the percentage of total bone (TB) volume (%BIC–%TB).)

Machined (turned) implant surfaces are not prepared to a uniform surface texture but can vary in roughness according to the selected grade of titanium, shape and sharpness of the cutting instruments, and type of manufacturing procedures used. Machined implant surfaces are generally classified as smooth or minimally rough with average surface roughness (Sa) values that reportedly range from 0.5 to 1 μm. In contrast, many implant manufacturers also blast, acid etch, oxidize, coat, or use a combination of procedures to further texture machined implant surfaces to produce topographies that are classified as intermediately rough (Sa = 1–2 μm) or rough (Sa = 2–3 μm). Although some attempts have been made to mathematically describe ideal surface pit morphology, dimensions and densities of biomechanical significance, there is currently no consensus on the degree of surface roughness that is optimum for bone cell attachment. Short-term clinical studies have reported that implants with intermediately rough or rough surfaces achieved greater bone-to-implant apposition and interfacial strength than did implants with machined surfaces. Few comparative studies have been published to date on BIC achieved with different roughened implant surfaces in human subjects, and long-term comparative data with machined surfaces are lacking.

Implant placement in the posterior maxilla is often complicated by deficiencies in the volume and quality of available bone. Grafting to increase bone volume (BV) in preparation for dental implant placement has been advocated for treating patients with severe atrophies. Few clinical studies have assessed how BIC is influenced by different implant surface textures in augmented bone. Bone-to-implant contact is traditionally evaluated by calculating the percentage of implant surface directly apposed to mineralized bone without discernable interposition of soft connective tissue at the light microscopic level. Albrektsson and Johansson hypothesized that at least 50% BIC is necessary for a stable prosthetic result, but this has not been clinically validated. Although clinical and radiographic examinations are useful in evaluating the treatment outcome of implants placed in sinus grafts, histologic analysis is the only reliable means of quantifying the percentage of BIC achieved in regenerated tissue.

The aim of this study was to analyze the BIC and OC of 6 different implant surfaces that were placed in the posterior maxillary jaws of humans, clinically loaded 60 days after placement, and retrieved for histomorphometric analyses after 6 months of functional loading.

**MATERIALS AND METHODS**

**Patient selection and evaluation**

Candidates for this study were consecutive patients from the first author’s (M.T.) private practice who presented with atrophic, edentulous posterior maxillae and met strict selection criteria (Table 1). Each candidate was subjected to a comprehensive diagnostic evaluation. Medical and dental histories were reviewed, and an oral examination was conducted to assess current health status and to identify any pathologies that required treatment before the study. A computerized tomography scan was conducted to ensure the total absence of sinus pathology and to evaluate the residual alveolar bone height and the bone quality. A mounted study cast with diagnostic wax-up was fabricated to evaluate jaw relationships, proposed implant locations, available occlusal dimensions, and crown-root ratios. A surgical template was also made to guide implant placement relative to the planned prosthesis.

Three adult patients (mean age = 45.2 years) with type IV bone in their edentulous posterior maxillary jaws and a mean residual sinus floor height of 3 mm were selected for the study. The case was thoroughly discussed with each patient, requirements for study participation were explained, and treatment alternatives were presented. Each patient
signed an informed consent form before admission into the study. This study was reviewed and approved by the Ethics Committee of the Lombardy Region Public Healthcare System.

**Augmentation material**
A composite graft consisting of deproteinized cancellous bovine bone (Bio-Oss, Geistlich Pharma, Wolhusen, Switzerland) and autogenous bone in a 3:1 proportion was used in all cases. The autogenous bone was harvested from the lateral wall of the sinus immediately before the grafting procedure. Two patients received bilateral sinus grafts, but the third patient received only a unilateral sinus graft (Table 2).

**Study implants**
Screw-design implants with 6 different surface treatments were placed in this study (Table 2).

**Titanium Plasma Sprayed**
The titanium plasma-sprayed (TPS) treatment (Spline TPS, Zimmer Dental Inc, Carlsbad, Calif) consisted of a rough surface\(^7,15,16\) grit blasted with aluminum oxide (Al\(_2\)O\(_3\)) and plasma sprayed with molten titanium particles to produce a porous surface topography. Although surface roughness data were not available on this coating because the manufacturer discontinued the implant, reported Sa values for TPS coatings have been reported to range from 3.60 ± 0.30 μm to 9.90 ± 1.06 μm.\(^{32}\)

**Microtextured**
Microtextured treatment (Tapered Screw-Vent MTX, Zimmer Dental Inc) consisted of a rough surface\(^7,15,16\) grit blasted with hydroxyapatite (HA) and sequentially washed in non-etching nitric acid and distilled water baths to remove manufacturing residue.\(^7\) The result is a fairly uniform surface of closely spaced micropits\(^33\) with a reported Sa value of 3.30 ± 0.22 μm.\(^{32}\)

**Oxidized**
Oxidized treatment (MKIII TiUnite, Nobel Biocare, Yorba Linda, Calif) consisted of a rough surface\(^7,15,16\) commercially oxidized through a process of anodization. The oxidized surface ranges from 1 to 10 μm in thickness, contains numerous pores of varying sizes,\(^34,35\) and has a reported Sa value of 3.14 ± 0.11 μm.\(^{32}\)

**Sandblasted and Acid Etched**
Sandblasted and acid-etched treatment (ITI SLA, Straumann USA, Andover, Mass) consists of a rough surface\(^7,15,16\) sandblasted with 250- to 500-μm corundum grit, etched in hydrochloric (HCl) and sulfuric (H\(_2\)SO\(_4\)) acids, and washed in deionized water to remove manufacturing residue.\(^36\) The surface is characterized by wide variations in surface topography created by the sandblasting and acid-etching processes\(^35,36\) and has a reported Sa value of 3.32 ± 0.22 μm.\(^{32}\)

**Acid Etched**
Acid-etched treatment (Osseotite, 3i Biomet Inc, Palm Beach Gardens, Fl)

---

**Table 1**

<table>
<thead>
<tr>
<th>Inclusion Criteria</th>
<th>Exclusion Criteria</th>
</tr>
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<tbody>
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<td>Deficient maxillary posterior ridge 2 to 4 mm in height unilaterally or bilaterally Non-smoker Willingness to participate in the study and to provide signed informed consent Physically healthy and mentally stable Free of periodontal disease</td>
<td>Pathological conditions of the sinus (eg, sinusitis, cysts, tumors) Current or past radiotherapy in the surgical zone Serious medical condition (eg, recent myocardial infarction, severe renal disorder) Immunosuppressive therapy (eg, corticosteroids) Failure to meet any inclusion criterion</td>
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**Table 2**

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<td>Oxidized</td>
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<td>3.75</td>
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<tr>
<td>3</td>
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<td>TPS‡</td>
<td>Plasma coated</td>
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<tr>
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<td></td>
<td>Right</td>
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<td>3.75</td>
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<tr>
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<td></td>
<td>Native</td>
<td>Osseotite*</td>
<td>Plasma coated</td>
<td>13</td>
<td>3.75</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Native</td>
<td>Hydroxyapatite*</td>
<td>Plasma coated</td>
<td>13</td>
<td>3.75</td>
<td></td>
</tr>
</tbody>
</table>

*Zimmer Dental Inc, Carlsbad, Calif.
†Nobel Biocare, Yorba Linda, Calif.
‡Straumann USA, Andover, Mass.
§3i Biomet Inc, Palm Beach Gardens, Fla.
Histomorphometric Evaluation

Fla) consists of an intermediately rough surface\(^7\)\(^\text{15,16}\) chemically etched in HCl and H\(_2\)SO\(_4\) to produce a fairly uniform surface of small peaks and valleys.\(^37\) The surface has a reported Sa value of 1.82 \(\pm\) 0.08 \(\mu\)m.\(^31\)

**Hydroxyapatite**

Hydroxyapatite treatment (HA coated: Spline Twist HA, Zimmer Dental Inc) consists of a rough surface\(^7\)\(^\text{15,16}\) grit blasted with Al\(_2\)O\(_3\), plasma sprayed with HA, and heat treated to increase crystallinity.\(^38,39\) The average roughness (average peak height) value of the coating has been reported to be 4.9 \(\mu\)m,\(^38\) but Sa values have not been reported for this surface in the dental literature.

**Antibiotic regimen**

The total number of bacteria in the human mouth is believed to exceed the population of the entire earth, and a single tooth surface may harbor 1000 to 100 000 bacteria of more than 300 species at any given time.\(^40\) Although some oral bacteria are benign, others can cause a variety of opportunistic infections.\(^40\) The rationale for antibiotic prophylaxis is to curb or prevent surgical sepsis rather than to treat an acute infection.\(^41\) Prophylactic antibiotics are indicated for sinus grafting and dental implant placement, which pose the risk of introducing new bacteria into the sinus and nose.\(^42\) It has been demonstrated that high-dose antibiotics administered before a surgical procedure not only minimize the incidence of postoperative infection\(^41\) but also significantly reduce the rate of implant failure through stage 2 surgery.\(^42\) All patients in this study were prescribed amoxicillin trihydrate (Velamox, GlaxoSmithKlein, Brentford, Middlesex, UK) (2 g 1 hour before surgery; 1 g 6 hours and 12 hours later). Postoperative antibiotic therapy proceeded for 7 days (2 g/d).

**Surgical procedures**

**Sinus Augmentation Surgery**

Each patient was prepared for surgery and anesthetized via local infiltration with articaine hydrochloride 4% and epinephrine (Ultracaine DS Forte, Hoechst Marion Roussel Adventis, Kansas City, Mo) (1:100 000). A midcrestal incision was made from the tuberosity region to the canine fossa region with a No. 15 Bard-Parker scalpel (BD Medical Systems, Franklin Lakes, NJ). Two vertical releasing incisions were made, and a full-thickness flap was elevated with a curette to expose the lateral wall of the sinus vertically to the buccal vestibular fold. A No. 6 round diamond bur (Horico, Hopf Ringleb & Co GmbH & Cie, Berlin, Germany) was used in a straight handpiece under copious external irrigation to cut the sides of the window osteotomy. Curettes were used to carefully remove the cortical plate from the osteotomy window and to elevate the Schneiderian membrane without laceration. The prepared augmentation material was placed in the void between the elevated membrane and the residual sinus floor. The excised facial plate fragment was replaced over the osteotomy window and the soft tissues were approximated and sutured (4.0 Vicryl, Ethicon Johnson & Johnson, Sommerville, NJ). Ibuprofen (Motrin, Procter & Gamble, Cincinnati, Ohio) was prescribed as an analgesic for use on the day of surgery (600 mg 1 hour before and 10 hours later) and for 2 days postoperatively. Each patient used a 0.2% chlorhexidine digluconate mouth rinse twice a day for 10 days, at which time the sutures were removed.

**Implantation and Loading**

Implantation was performed 6 months after grafting (Table 2). Patients 1 and 2 received 1 implant with a different surface bilaterally in maxillary posterior sinus grafts. Patient 3 received 2 implants in a unilateral sinus graft and 2 implants with the same 2 surfaces contralaterally in native bone for comparative purposes. All implants were 13 \(\times\) 3.75 mm, except the sandblasted and acid-etched implants (12 \(\times\) 4.1 mm), and each implant was placed according to the standard protocol of its manufacturer. Because the use of human subjects for the placement and subsequent retrieval of dental implants for analysis purposes is a sensitive ethical issue, only 1 sample of each implant type was placed in this study. After 60 days, each implant was restored with a gold-ceramic crown that was placed into full occlusal loading by the opposing natural dentition in the lower jaw.

**Implant Retrieval**

Six months after clinical loading, the peri-implant mucosa at all implant sites appeared to be healthy and nonpainful to percussion, and there was no evidence of bleeding on probing or peri-implant radiographic translucency. At this time, osteotomy lines were cut 3 mm from the implant surface with a tungsten drill under copious irrigation. The implants were carefully removed with the surrounding tissue from the patients in block sections to maintain the bone-implant interface, and the specimens were immediately fixed in 10% formalin. Each extraction site was regrafted with the same composite graft material, and new implants were placed and subsequently restored after 6 months of healing.
**Sample Preparation**

The retrieved specimens were dehydrated in ethanol and sequentially infiltrated in a starting solution of 50% ethanol:resin and then in 100% resin Remacryl resin (experimental resin provided by Mr Cesare Scala) and processed to obtain thin ground sections. Toluidine blue and basic fuchsin staining were used to distinguish the fibrous tissue and to improve contrast. Digitized images were made with a JVC TK-C1380 Color Video Camera (JVC Victor Company, Tokyo, Japan) and a frame grabber and then morphometrically analyzed by image-analysis software (IAS 2000, Delta Sistemi, Rome, Italy).

For each implant, the 2 most central sections were analyzed according to 5 histologic parameters: percentage of total bone (TB) volume, mean percentage of BIC, percentage of vital BV, percentage of graft volume (GV), and total volume (TV).

**Percentage of TB volume.** This parameter indicated the surface area occupied by the bone matrix plus graft particles over the entire microscopic field. It was measured by outlining the bone surfaces and the graft area to determine the surface area of bone and graft in the microscopic field.

**Mean percentage of BIC.** This parameter indicated the surface of the implant directly apposed by bone matrix and was expressed as the percentage of the implant surface at each side and for each section. Two different counts and percentages were calculated by considering only 1 side as the total length of the implant interface. Student t test was applied to compare the mean BIC values of the 2 surfaces.

**Percentage of vital BV.** This parameter indicated the percentage of vital bone in the grafted sinus and was expressed as the percentage of the total surface and percentage of the BV.

**Percentage of GV.** This parameter indicated the amount of graft still present in the sinus and was expressed as the percentage of the total surface and percentage of the BV.

**Total volume.** This parameter indicated the entire area of the microscopic field.

**Patient Retreatment**

After removal of the study samples, the extraction sites were regrafted, implants (Tapered Screw-Vent MTX) were subsequently placed 6 months after healing, and all 3 patients were successfully restored with fixed restorations after osseointegration was confirmed.

**Histologic Results**

At the time of prosthesis delivery, the acid-etched implant placed in the sinus lift of patient 3 became mobile and sore and was removed (Table 3). All other implants osseointegrated. Healing was uneventful and no complications were observed in any other patients. Histologic and histomorphometric results are summarized in Table 3.

**TPS surface in grafted bone**

Basal bone was indistinguishable from regenerated peri-implant bone, which had graft particles interspersed throughout nearly all of it (Figure 1a). Bone density was high (TB = 61.95%) around the implant, with thick bony trabeculae characterized by composite bone with new primary osteons (Figure 1b). The trabeculae were also well connected with a few graft particles (GV = 11.50).

<table>
<thead>
<tr>
<th>Surface</th>
<th>Type</th>
<th>Total Bone (TB)/Total Volume, %</th>
<th>Vital Bone Volume/Total Volume, %</th>
<th>Graft Volume/Total Volume, %</th>
<th>Bone-to-Implant Contact (BIC), %</th>
<th>Osteoconductive Capacity of the Implant Surface (%BIC-%TB), %</th>
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</thead>
<tbody>
<tr>
<td>TPS</td>
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<td>NA</td>
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<td>Hydroxyapatite</td>
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*NA indicates not applicable; TPS, titanium plasma-sprayed; MTX, microtextured treatment; TiUnite, oxidized treatment; SLA, sandblasted and acid-etched treatment.
†Implant failed to integrate.
FIGURE 1. (a) Titanium plasma-sprayed (TPS) surface in graft: General overview shows peri-implant bone with few graft particles and thick bony trabeculae (Toluidine blue, original magnification \( \times 8 \)). (b) TPS surface in graft: Thick peri-implant trabeculae of composite bone (arrows) and new primary osteons (O) (Toluidine blue, original magnification \( \times 50 \)). (c) TPS surface in graft: The new bone contacted only the crests (tips) of the threads (arrows) (Toluidine blue, original magnification \( \times 25 \)). (d) TPS surface in graft: Amorphous interfacial structures in some locations could be ascribed to bone powder (arrows). Small cracks in this region may be preparation artifacts (Toluidine blue, original magnification \( \times 100 \)). (e) TPS surface in graft: Bone resorption activity at the interface is evident through an osteoclast in the Howship’s lacuna (arrow) (Toluidine blue, original magnification \( \times 400 \)).
Vital BV accounted for 50.45% of the TV. No evidence of osteoconductivity was observed on the implant surface. Bone-to-implant contact first occurred at the level of the fourth to fifth thread and contacted the crests (tips) of the remaining implant threads but was absent in the locations of the thread roots (interthread regions) (BIC = 41.48%) (Figure 1c). In some areas, bone powder was interposed between the implant surface and the newly formed bony trabeculae (Figure 1b). Small cracks were seen in the thickness of the powder (Figure 1d), which could indicate a relatively weak region or may have been artifacts caused during sample preparation. Almost half of the bone surfaces were covered by osteoid bands, and bone resorption was mainly localized at the interface (Figure 1d and e) and at the crest. The mineralized bone matrix was composed of a central core of woven bone covered by layers of lamellar bone.

Microtextured surface in grafted bone

Basal bone appeared quite distinct from grafted bone (Figure 2a). The bone structure was dense (TB = 58.42%), but a large portion of the mineralized tissues contained graft particles (GV = 19.53%). Vital BV accounted for 38.89% of the TV. Almost all the peri-implant trabeculae in the...
FIGURE 3. (a) Oxidized surface in graft: Differences and limits between the basal bone (B) and the grafted region (R) were easily visible (asterisks). Bone structure was quite dense, but a high percentage of the mineralized tissues contained graft particles (Toluidine blue, basic fuchsin, original magnification ×8). (b) Oxidized surface in graft: Magnification of the regenerated tissues showed that many peri-implant trabeculae (B) contained embedded graft particles (G) and were quite thick and well connected. Most of the graft particles (G) were embedded in the newly formed bone and were not found in the marrow spaces (M) (Toluidine blue, basic fuchsin, original magnification ×25). (c) Oxidized surface in graft: Magnification of the previous case. The surfaces of the graft particles (G) exposed to the marrow spaces were covered by multinuclear giant cells (asterisk) and showed the typical white unstainable layer (B = bone, V = vessel, arrows = osteoclast) (Toluidine blue, original magnification ×200). (d) Oxidized surface in...
regenerated area contained embedded graft particles. Basal bone and regenerated bone differed in the thickness, connectivity, and number of bone trabeculae. The former was primarily composed of horizontal with some vertical connecting trabeculae (Figure 2a). In the latter, randomly arranged trabeculae varied in thickness and connections according to the shapes of the graft particles embedded within them (Figure 2b). At the microtextured surface interface, a continuity of bone layering was present in the basal bone, whereas a mix of bone, graft particles, and graft powder covered the implant surface in the regenerated area (Figure 2c). In the apical third of the implant, graft powder and particles were compacted onto the implant surface and immersed in a mineral matrix (Figure 2d). Bone-to-implant contact was very high (94.08%). The first point of bone contact with the implant surface was observed under the first thread.

**Oxidized surface in grafted bone**

The difference between the basal and regenerated bone was clearly visible (Figure 3a). Four to five threads were located in the basal native bone, whereas the remainder of the implant was in regenerated bone. The bone structure was quite dense (TB = 59.77%), but a high percentage of the mineralized tissues contained graft particles (GV = 15.4%). Vital BV accounted for 44.37% of the TV. Peri-implant trabeculae were quite thick and well connected, and many graft particles were embedded in the regenerated tissue (Figure 3b). The surfaces of the graft particles exposed to the marrow spaces were covered by multinuclear giant cells and showed the typical white unstable layer (Figure 3c). The native bone was composed mainly of thick horizontal trabeculae with vertical connectors. The implant surface clearly showed the thickness of the titanium-oxide coating and that it was well integrated to the newly formed bone (Figure 3d). In some regions, the titanium-oxide coating was detached from the implant surface, and some particles were found in macrophages several microns from the implant surface (Figure 3e and f). A thick continuous bone layer in the basal area covered the implant surface, whereas in the regenerated area newly formed bone, graft particles, and powder were apposed to the implant surface. In the apical vent of the implant, graft powder, pieces of particles, and bone debris were packed onto the implant surface with few cells interposed, which were mainly foreign-body giant cells. The overall percentage of BIC was quite high (77.32%).

**Sandblasted and acid-etched surface in grafted bone**

Overall bone density was very low (TB = 26.77%) (Figure 4a). The grafted area was localized to the apical third of the implant (GV = 2.81%), whereas the remaining peri-implant tissue was low-density native bone (BV = 23.96%). Despite the limited peri-implant bone density, however, the percentage of BIC was quite high (51.85%). A very thin layer of newly formed bone was adapted to the sandblasted and acid-etched surface, particularly at the level of the threads (Figure 4b). The noncortical crestal bone was very thin, and the peri-implant trabeculae were not well connected to each other or to the bone apposed to the implant surface. Bone density and connectivity were more pronounced at the level of the grafted area (Figure 4c). In this region, graft particles of varying sizes were embedded in newly formed bone trabeculae.

**HA surface in grafted bone**

Very thin native basal bone was present and the graft was located at the most coronal portion of the peri-implant bone (Figure 5a). The bone structure was quite dense, but the high volume of graft particles (GV = 17.36%) reduced the amount of the vital bone (BV = 28.53%) within the TV of mineralized bone (TB = 45.89%). Embedded graft particles arranged in a disordered and inhomogeneous way were present throughout the peri-implant trabeculae. The first BIC was at the level of the first thread, and the bone matrix was
FIGURES 4 AND 5. Figure 4. (a) Sandblasted and acid-etched surface in graft: General overview of the SLA implant. The graft area is limited to the apical side of the peri-implant bone. The bone structure is poor with thin and brittle trabeculae (Toluidine blue, basic fuchsin, original magnification ×8). (b) Sandblasted and acid-etched surface in graft: Magnification of the previous implant is in rectangle A. A very thin layer of newly formed bone was adapted on the sandblasted and acid-etched surface, particularly at the level of the threads (Toluidine blue, basic fuchsin, original magnification ×25). (c) Sandblasted and acid-etched surface in graft: Magnification of the previous implant is in rectangle B corresponding to the sinus grafted region. The bone (B) is denser at this level and the connectivity is more pronounced. Many different-sized graft particles (G) are embedded in the newly formed bone trabeculae (M = marrow tissues, IT = implant thread) (Toluidine blue, basic fuchsin, original magnification ×25).
mainly structured as composite bone with large osteocytes and external lamellar layers. The HA coating was clearly visible with a well-preserved structure and thickness (Figure 5b). Almost all the surface was covered by bone except for the most apical threads surrounded by many graft particles and little vital bone (Figure 5c). A layer of normal bone was present throughout the bone-HA interface, even when the graft particles or powder were almost contacting the implant surface. The overall percentage of BIC was quite high (74.51%).

**HA surface in native bone**

Because the implant was positioned in basal bone, graft particles were not present and the TB corresponded to the BV. The general bone structure consisted of very low-density native bone (TB 28.64%); nevertheless, excellent BIC (59%) was observed (Table 3). Small and thin trabeculae were very close to the implant surface, and the BIC began below the first thread (Figure 6a and b). Bone-to-implant contact was present on the tip of the thread and in the interthread region and showed continuity in the third apical area.

**Acid-etched surface in native bone**

Although the acid-etched implant was placed mesial to the HA implant in native bone, the basal bone around the acid-etched surface was significantly denser (TB = 45.03%). Bone-to-implant contact (69.03%) extended from the second thread on the right side of the implant but was present on the fourth and fifth threads on the left side of the implant (Figure 7a). Mineralized bone was observed in intimate contact with the acid-etched surface (Figure 7b).

**Morphometric Results**

The BIC obtained with the 6 different implant surfaces is presented in Table 3. The OC of each implant surface was calculated by establishing the difference between the percentage of BIC and the percentage of TB; the greater the difference between the two, the better the OC performance of the implant surface. All the implants except TPS showed BIC that was higher than the TB of the site in which the implant was placed. The microtextured implant surface exhibited the greatest OC (%BIC–%TB) in grafted bone (34.31%), followed by HA (28.62%), sandblasted and acid-etched (25.08%), oxidized (17.55%), and TPS (–20.47%). In native bone, the HA surface exhibited a higher OC (30.39%) than did the acid-etched surface (24.0%).

**Discussion**

Because autogenous bone is compatible with the host tissues, readily available and able to grow new bone by all 3 currently known regenerative processes (ie, osteoconduction, osteoinduction, and osteogenesis), it is considered the gold standard of augmentation materials.\(^{43}\) Drawbacks to the use of autogenous bone grafts include limitations in the dimensions, quality and quantity of obtainable bone,\(^{44}\) increased operating time and cost for graft harvesting, and donor site morbidity.\(^{45}\) A variety of banked heterogeneous bone and alloplastic materials are commercially available as supplemental or alternative graft materials, though none heal as predictably as fresh autografts.\(^{46,47}\) For example, xenografts reportedly lack the osteoinductive or osteoconductive properties found in native bone\(^{38,49}\) but can still undergo physiologic remodeling and become incorporated into bone over time.\(^{48,50}\) In the present study, a composite graft was selected to combine the economy of a xenograft with the biological advantages of autogenous bone. The slower rate of turnover by the xenograft into new bone was evident in many of the histologic samples (Figures 2, 3a and d, 4, 6, 7).

All the osseointegrated implants in this study achieved very close BIC with new bone, but small pockets of graft particles were present between the implant threads. A possible explanation of this phenomenon may be that graft chips were entrapped within the fractured bony trabeculae through primary contact with the implant surface during placement. Evidence of encapsulation

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**Figure 5.** (a) Hydroxyapatite (HA) surface in graft: General overview of the HA-coated implant. The graft area is spread all around the peri-implant bone. The bone structure is dense but the trabeculae are inconsistently arranged (Toluidine blue, basic fuchsin, original magnification ×8). (b) HA surface in graft: Magnification of the HA-coated implant. The coating (arrows) was clearly visible with a well-preserved structure and thickness and a high percentage of osseointegration (B = bone; G = graft particles) (Toluidine blue, basic fuchsin, original magnification ×25). (c) HA surface in graft: Magnification of the apical part of the HA-coated implant. The most apical threads were surrounded by many graft particles and a small amount of vital bone. However, the HA-coating (arrows) was layered by a continuous bony trabeculum (B = bone, G = graft particles) (Toluidine blue, basic fuchsin, original magnification ×25).
by new lamellar bone suggested that turnover of the graft particles was in progress.

In all cases except for the TPS surface, the percentage of BIC was significantly higher (1.3 times to 1.7 times) than the percentage of TB surrounding the implant (Table 3). Studies have shown that the higher the percentage of BIC, the faster and firmer the bone integration but that the development of BIC is dependent on the implant surface, bone density, and healing time.27 The differences in percentages between TB and BIC in determining the OC of the implant surface has been previously discussed in depth by Trisi et al.14,27 At lower levels of TB (29.58%–45.89%),27 the implants achieved 1.6 to 1.8 times greater BIC, except for the TPS surface (Table 3). It is interesting to note that these good histomorphometric results were obtained with implants that were subjected to early loading. Another interesting finding was that, after 6 months of loading, there were no histomorphometric differences between implants placed in native or regenerated bone.

Titanium particulate debris that is partially dislodged or folded over onto the surface of machined implants from the manufacturing process has been reported in the dental literature.51 Schliephake et al.52 observed that such titanium fragments abraded and lodged on the bone surface next to machined implants placed in minipigs. After a period of 5 years, the fragments were found...
to have migrated into concentrations located primarily in the lungs and secondarily in the livers and kidneys of the animals.\textsuperscript{52} Fragments of TPS-coated surfaces have also been observed in the soft and hard tissues adjacent to implants.\textsuperscript{53} It is important to note, however, that a comprehensive literature search (MEDLINE) revealed no reports of deleterious effects from abraded metallic particulate matter in humans. Matthew and Frame\textsuperscript{54} reported that tissue response to abraded metal particles in an animal model was variable and dependent on their location; some particles were covered by fibrous tissue or enclosed in bone, whereas others were intracellular.

In the present study, fragments of the oxidized surface were observed to have abraded from the implant and embed in soft marrow tissue near new bone (Figure 3b). This particulate matter may have ultimately resulted in encapsulation by the regenerating hard tissue.

Ethical considerations in retrieving asymptomatic, well-functioning osseointegrated implants from human subjects for the purposes of scientific research necessitated a severe limitation in the number of study participants and samples involved. For this reason, the findings of this study should be considered preliminary to further histologic research on roughened implant surfaces.

**Conclusion**

The microtextured surface achieved the greatest BIC (94.08\%) and demonstrated the most OC (34.31\%), whereas the poorest results were achieved by TPS in both categories (41.48\% for BIC and –20.47\% for OC). All other surfaces demonstrated excellent BIC (>50\%) but varied widely in surface osteoconductivity (range = 17.55\%–28.62\%).

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**References**

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